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**Research article**

# Muscle strength and qualitative jump-landing differences in male and female military cadets: The jump-ACL study

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**Abstract**
Recent studies have focused on gender differences in movement patterns as risk factors for ACL injury. Understanding intrinsic and extrinsic factors which contribute to movement patterns is critical to ACL injury prevention efforts. Isometric lower-extremity muscular strength, anthropometrics, and jump-landing technique were analyzed for 2,753 cadets (1,046 female, 1,707 male) from the U.S. Air Force, Military and Naval Academies. Jump-landings were evaluated using the Landing Error Scoring System (LESS), a valid qualitative movement screening tool. We hypothesized that distinct anthropometric factors (Q-angle, navicular drop, bodyweight) and muscle strength would predict poor jump-landing technique in males versus females, and that female cadets would have higher scores (more errors) on a qualitative movement screen (LESS) than males. Mean LESS scores were significantly higher in female (5.34 ± 1.51) versus male (4.65 ± 1.69) cadets ($p < 0.001$). Qualitative movement scores were analyzed using factor analyses, yielding five factors, or "patterns", contributing to poor landing technique. Females were significantly more likely to have poor technique due to landing with less hip and knee flexion at initial contact ($p < 0.001$), more knee valgus with wider landing stance ($p < 0.001$), and less flexion displacement over the entire landing ($p < 0.001$). Males were more likely to have poor technique due to landing toe-out ($p < 0.001$), with heels first, and with an asymmetric foot landing ($p < 0.001$). Many of the identified factor patterns have been previously proposed to contribute to ACL injury risk. However, univariate and multivariate analyses of muscular strength and anthropometric factors did not strongly predict LESS scores for either gender, suggesting that changing an athlete's alignment, BMI, or muscle strength may not directly improve his or her movement patterns.

**Key words:** Jump-landing, ACL injury risk, motor patterns, qualitative movement screen.

## Introduction

Injury to the anterior cruciate ligament (ACL) is a common and devastating injury in young, active populations. The risk of non-contact ACL injury for females is more than twice that of males in many sports (Engstrom et al., 1991; Arendt and Dick, 1995; Bjordal et al., 1997; Arendt et al., 1999). Despite previous work suggesting specific movement patterns may be responsible for much of the increased ACL injury risk in females (Hewett et al., 1999; Mandelbaum et al., 2005; Onate et al., 2005), the reasons for this marked disproportion in risk between genders remains an area of active investigation. Gender-specific differences have been shown during the performance of common athletic tasks such as cutting, stopping, and jumping (Malinzak et al., 2001; Chappell et al., 2002; Decker et al., 2003; Ferber et al., 2003; Ford et al., 2005; Chappell et al., 2007). Specific variations in movement patterns during the early landing phase following a jump have also been established (Chappell et al., 2002; Ford et al., 2003; Chappell et al., 2007) and are particularly important since landing from a jump is the most common mechanism for ACL injury in both genders (Shimokochi and Shultz, 2008). Traditionally differences in movement patterns have been evaluated using laboratory biomechanical measurements. However such methods are impractical for screening large cohorts. The ability to identify high-risk movement patterns in a large population using a quicker but reliable alternative, such as a qualitative movement screen, is crucial for large-scale injury screening and prevention efforts.

If movement patterns are important risk factors for injury, then understanding how anthropometric traits and muscle strength influence these patterns is also important. Previous studies have found that female athletes have more navicular drop, larger Q-angles, weaker hamstrings and different ratios of quadriceps/hamstrings strength than male athletes (Colby et al., 2000; Lephart et al., 2002; Myer et al., 2009). Women also land from a jump with less knee flexion and more knee valgus than population-matched males (Ford et al., 2003; Chappell et al., 2007), which has been theorized to increase their risk of ACL injury. But the relationship between anthropometrics/strength variances and differences in knee flexion/valgus motion is not known. In other words, we do not know if women land with less knee flexion and more knee valgus *because* of their larger Q-angles, increased navicular drop and decreased quadriceps/hamstring strength ratios—or if differences in female movement patterns are primarily due to other factors. In part, this is because previous studies of athletic movement and anthropometrics have been in small cohorts with insufficient statistical power to perform these analyses (Fagenbaum and Darling, 2003; Chappell et al., 2007; Hughes et al., 2008). A large cohort analysis of jump-landing movement patterns, muscular strength, and anthropometrics could establish if strength and anthropometric factors predict specific landing movement patterns.

The main purpose of this paper was to use a qualitative movement screen to assess the jump-landing characteristics of a large cohort of young individuals at high risk for musculoskeletal injury. We analyzed the jump-

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landings of 2,753 physically-active military cadets using the Landing Error Scoring System (LESS). Additionally, we employed factor analysis to determine which landing patterns tended to exist concurrently. We used regression techniques to determine if anthropometric factors (BMI, navicular drop, Q-angle) and lower-extremity muscle strength contributed to observed differences in landing movements. We hypothesized that female cadets would have higher scores (more errors) on the qualitative movement screen (LESS) than male cadets and that the strength and anthropometric factors contributing to specific movement patterns would be different for male and female cadets.

## Methods

Data was collected as part of a larger project, the JUMP-ACL study. JUMP-ACL is a prospective cohort study of risk factors for ACL injury that enrolled subjects over a 5-year time period. This paper addresses one of the specific aims of the JUMP-ACL study, to describe gender differences in landing movements, in relation to anthropometrics and muscle strength.

### Subjects

2,753 cadets (n = 1,046 females, n = 1,707 males, ages 18-24; 38% of entering population during study period) at the U.S. Air Force, Military and Naval Academies participated in the study during their initial summer of training at the academies. Informed consent was obtained from each participant in accordance with each institution's review board. Cadets with a musculoskeletal injury to the lower extremity or who were otherwise unable to perform the study tasks at the time of data collection were excluded.

### Anthropometrics

Subject anthropometrics and postural alignment were obtained, including height, weight, BMI, navicular drop and Q-angle. A group of Certified Athletic Trainers (ATs) who travelled to each study site assessed all measurements using uniform procedures. In order to minimize collection error, all ATs received standardized training and had to pass a validation assessment before collecting field data. Navicular drop was assessed using a modification of the Brody method, and measured the vertical change in the position of the navicular tuberosity from a sitting to standing position (Brody, 1982). Static standing Q-angle was measured with a standard long-arm goniometer. The centre of the patella, apex of the anterior superior iliac spine (ASIS) and tibial tuberosity were marked with a permanent marker for visual reference during measurement (Woodland and Francis, 1992). The stationary arm was placed in line with the ASIS while the rotating arm in line with the tibial tubercle and the angular measurement in degrees was recorded. Three separate readings for each measurement were recorded and averaged. Intrarater reliability from pilot data showed good reliability for both navicular drop (intraclass correlation coefficient $[ICC]_{2,k} = 0.79$) and Q-angle ($ICC_{2,k} = 0.83$).

### Muscle strength

Isometric strength of the major muscles of the lower extremity was assessed using a hand-held dynamometer (NexGen Ergonomics, Quebec, Canada). Mean and peak isometric strength of the hamstrings, gluteus maximus, gluteus medius, quadriceps, hip external rotators, and hip internal rotators were assessed. The mean force measurement from two 5-second trials was averaged together. All strength values were recorded in Newtons and normalized to the subject's body weight (Newtons/weight in kilograms*9.807) before averaging. Intrarater reliability ($ICC_{2,k}$) ranged from 0.73 to 0.98. The full description of the muscle testing techniques can be found in Table 1.

### Landing technique: the Landing Error Scoring System (LESS)

Subjects performed a double-leg jump from a 30cm platform, landing out in front of the platform with both feet at a distance of approximately half their body height and then immediately jumping upwards as high as possible (Figure 1). Subjects were given verbal instruction on the task and allowed two practice jumps before the three jump trials were recorded. If the subject did not jump to

**Table 1. Lower extremity muscle strength testing techniques.**

| Muscle Group | Description of Testing Technique |
|---|---|
| **Quadriceps** | Subject seated, test leg in 90° of knee flexion. The dynamometer was placed over the anterior aspect of the subject's shank just proximal to the ankle joint. The subject was instructed to extend their knee with maximal effort. |
| **Hamstrings** | Subject prone, test leg in 90° of knee flexion. The dynamometer was positioned over the posterior aspect of the subject's shank just proximal to the ankle joint. The subject was instructed to flex their knee with maximal effort. |
| **Hip External Rotators** | Subject prone, test leg in 90° of knee flexion and neutral hip rotation. The dynamometer was placed over the medial aspect of the subject's shank just proximal to the ankle joint. The subject was instructed to externally rotate their hip with maximal effort. |
| **Hip Internal Rotators** | Subject prone, test leg in 90° of knee flexion and neutral hip rotation. The dynamometer was placed over the lateral aspect of the subject's shank just proximal to the ankle joint. The subject was instructed to internally rotate their hip with maximal effort. |
| **Gluteus Maximus** | Subject prone, test leg in 90° of knee flexion. The dynamometer was placed over the posterior aspect of the subject's thigh just proximal to the knee joint line. The subject was instructed to extend their hip with maximal effort while keeping their knee in the flexed position. |
| **Gluteus Medius** | Subject side lying, test leg in neutral hip extension and aligned parallel with their torso. The dynamometer was placed over the lateral aspect of the subject's thigh just proximal to the knee joint line. The subject was instructed to abduct their hip with maximal effort. |

**Figure 1. Jump-Landing Task: Participants jumped from a 30cm high box onto a forceplate and then immediately rebounded back up in a maximal jump.**

the required horizontal distance or did not vertically jump after the initial landing, that trial was discarded and the jump-landing manoeuvre repeated.

Two tripod-mounted digital camcorders recorded a frontal and sagittal view of each jump, at a distance of 16 and 13 feet, respectively. Cameras were levelled using the built-in level on each tripod. All jump-landing videos were analyzed at a later time by trained raters using the Landing Error Scoring System (LESS) (Boling et al., 2005; DiStefano et al., 2009; Padua et al., 2009). The LESS is a clinical assessment tool that reliably identifies individuals with potentially high-risk biomechanics (Padua et al., 2009). Jump-landing quality is assessed by analyzing videotapes of the jump-landing task in the sagittal and frontal planes. Scoring is based on the presence or absence of specific landing characteristics as described in the Appendix. Individually scored items are totalled to create an overall LESS score (range 0-17), with higher scores (more errors) indicative of higher-risk landing technique. Overall LESS scores were averaged over three valid jump trials for analyses.

### Data analysis

Independent t-tests were used to compare gender mean differences for subject anthropometrics, strength values, and overall LESS score. Separate univariate and multivariate linear regressions were used to determine the predictive validity of subjects' anthropometrics and muscle strength using overall LESS score as the dependent variable. Individual models for males and females were fit so as to assess gender-specific relationships.

Additionally, factor analysis was performed on individual LESS items to identify inter-related movement errors [*For factor analysis, a positive score on individual LESS items was defined as an Error if was judged to occur on at least 2 of 3 trials (items 1-15)*]. We used varimax rotation and iterated analyses. Two "general purpose" items on the LESS (#16 and #17) were excluded from analysis because of possible collinearity with the other 15 items. Regression diagnostics indicated no collinearity in the remaining LESS items (largest condition index of 4.6). Pooled variance t-tests were used to compare factor means between genders as well as factor frequency by gender. The significance level for all analyses was set a priori at $\alpha = 0.05$.

## Results

### Landing technique: the Landing Error Scoring System (LESS)

Total overall Landing Error Scoring System (LESS) scores were significantly different ($p < 0.001$) for males and females. Males' mean score was 4.65 ± 1.69 (Range 0.00-10.67). The mean score for females was 5.34 ± 1.51(range 0.33-11.00).

Factor analysis is a statistical method used to detect structure in the relationships between variables, or in other words, identify patterns among the observed variables. Using data from individual LESS items, factor analyses revealed five groups of related errors (orthogonal factors): Factor 1 - decreased sagittal trunk, hip and knee flexion at initial ground contact (LESS Items L3, L2,and L1); Factor 2 - valgus knee and feet wide at initial contact (Items L5 ,L15, and L7); Factor 3 - toes out and knees flexed at initial contact (Items L10 and L1); Factor 4 - heelstrike landing and asymmetric footstrike landing; (Items L4 and L11) and Factor 5 - less sagittal flexion over the landing phase (Items L12, L13, and L14). These five factors all had Eigenvalues greater than one, and collectively accounted for 67% of the covariance between the 15 LESS items.

Pooled variance t-tests between genders on these 5 factors showed that females were significantly more likely than males to land with: less hip and knee flexion at initial contact (Factor 1, $p < 0.001$); more knee valgus and wider landing stance (Factor 2, $p < 0.001$); and less flexion displacement over the entire landing phase (Factor5, $p < 0.001$). Males were more likely than females to land with toe-out (Factor 3, $p < 0.001$) and had a higher prevalence of heel landing and asymmetric foot landing (Factor 4, $p < 0.001$) (See Table 2).

### Anthropometrics and strength

Anthropometrics by gender are given in Table 3. Muscle strength data is shown in Table 4. Independent t-tests

**Table 2.** Number of subjects scoring an error for each factor [1,2].

| Factor | | Male (N=1707) N | Male (N=1707) % | Female (N=1046) N | Female (N=1046) % |
|---|---|---|---|---|---|
| Factor 1 | Poor Sagittal Flexion – Stance | 559 | 32.8% | 448 | 42.6% |
| Factor 2 | Valgus Knee & Feet Too Wide | 428 | 25.1% | 386 | 36.7% |
| Factor 3 | Toes Out & Knees Flexed | 503 | 29.5% | 154 | 14.6% |
| Factor 4 | Heelstrike & Uneven Footstrike | 751 | 44.1% | 273 | 26.0% |
| Factor 5 | Poor Sagittal Flexion – Landing | 582 | 34.1% | 472 | 44.9% |

[1] Factors generated from factor analysis loading. [2] For items 1-15, a positive score was defined as an Error on at least 2 of 3 trials. For items 16 & 17, a positive score was defined as Average on at least 2 of 3 trials or Poor/ Stiff on at least 1 of 3 trials.

showed that males and females were significantly different for all investigated anthropometric (height, weight, BMI, navicular drop, and Q-angle) and strength variables (Tables 3 and 4).

**Table 3.** Subject biometrics. Data are means (±SD).

| | Males (n = 1,607) | Females (n = 994) |
|---|---|---|
| Height (m) | 1.78 (.07) | 1.66 (.07) * |
| Weight (kg) | 77.4 (12.3) | 63.0 (7.8) * |
| Body Mass Index | 24.3 (3.1) | 22.9 (2.3) * |
| Navicular Drop (mm) | 7.5 (2.8) | 7.0 (2.6) * |
| Q-Angle (º) | 8.6 (4.5) | 11.6 (4.9) * |

* $p < 0.001$

**Table 4.** Muscle strength normalized to body mass ($N \cdot kg^{-1}$). Data are means (±SD).

| | Males (n = 1,607) | Females (n = 994) |
|---|---|---|
| Quadriceps | .49 (.09) | .41 (.09) * |
| Hamstrings | .24 (.05) | .21 (.05) * |
| Hip external rotation | .21 (.04) | .17 (.03) * |
| Hip internal rotation | .19 (.04) | .18 (.04) * |
| Gluteus maximus | .26 (.07) | .23 (.07) * |
| Gluteus minimus | .34 (.08) | .30 (.07) * |

* $p < 0.001$

## Predicting poor landing

Due to missing data values, univariate and multivariate regression models were analyzed for 2,734 participants (females = 1046; males = 1688). Univariate analysis for males indicated that low BMI, increased Q-angle, and poor gluteus medius strength were individually predictive of poor landing technique (higher LESS score). However as a group, multivariate modelling showed extremely limited predictive value (combined $R^2$=.016; $p < 0.01$) and only lower BMI and weak hip internal rotation strength significantly contributed to poorer landing technique (Table 5). For females, univariate analyses suggested that weaker hamstrings and weaker gluteus medius strength were important predictors of poorer jump-landing (Table 6). However, in contrast to males, we were not able to strongly predict specific contributors to landing error in females with multivariate analysis ($p = 0.098$). Again, the predictive value of all these variables as a group was very limited (combined $R^2 = 0.014$).

# Discussion

## Movement pattern differences can be assessed by the LESS

The ability to quickly and reliably identify individuals at high risk of injury is critical to injury prevention efforts. Because high-risk movement patterns have been linked to ACL injury risk (Hewett et al., 2005; Krosshaug et al., 2007), the ability to rapidly screen for these movement patterns could facilitate the implementation of large-scale injury prevention efforts. Our results indicate that a qualitative movement screen, the Landing Error Scoring System (LESS) can accurately characterize the jump-landing characteristics of a large cohort of males and females. Females demonstrated poorer overall landing technique (5.34 ± 1.51 vs. 4.65 ± 1.69 for males) and showed less knee flexion, less hip flexion and more valgus collapse. These results are similar to studies of common movement tasks using traditional laboratory biomechanics (Chappell et al., 2002; Hewett et al., 2006; Malinzak et al., 2001; Padua et al., 2009). Previous work has shown that LESS score is correlated with high-risk movement patterns as measured by traditional motion analysis (Padua et al., 2009). Taken together these results suggest that the LESS accurately characterizes jump-landing movements. The results of the present investigation do not allow us to determine which differences are specifically correlated

**Table 5.** Univariate and multivariate regression results – Males.

| Variable | Univariate [1] β | SE | t-value | p-value | Multivariate [1] β | SE | t-value | p-value |
|---|---|---|---|---|---|---|---|---|
| BMI | -.091 | .321 | -3.77 | <.005 * | -.086 | .014 | -3.21 | .001 * |
| Q-Angle | .053 | .009 | 2.20 | .03 * | .028 | .010 | 1.10 | .27 |
| Navicular Drop | -.004 | .014 | -.18 | .86 | .007 | .015 | .28 | .78 |
| Quadriceps | -.046 | .438 | -1.89 | .06 | -.037 | .549 | -1.21 | 23 |
| Hip Ext. Rotators | -.010 | 1.043 | -.41 | .68 | .042 | 1.497 | 1.20 | .23 |
| Hip Int. Rotators | -.040 | 1.013 | -1.66 | .10 | -.070 | 1.466 | -2.00 | .05 * |
| Hamstrings | <.001 | .791 | -.04 | .97 | .012 | 1.064 | .38 | .71 |
| Gluteus Maximus | .021 | .561 | .86 | .39 | .040 | .651 | 1.41 | .16 |
| Gluteus Medius | -.050 | .509 | -2.06 | .04 * | -.046 | .656 | -1.48 | .14 |

*Statistically significant. [1] Univariate betas are not adjusted for any other variable; multivariate betas are adjusted for any other variables listed in the table.

**Table 6. Univariate and multivariate regression results – Females.**

| | Univariate [1] | | | | Multivariate [1] | | | |
|---|---|---|---|---|---|---|---|---|
| **Variable** | **β** | **SE** | **t-value** | **p-value** | **β** | **SE** | **t-value** | **p-value** |
| **BMI** | -.024 | .020 | -.77 | .44 | -.040 | .022 | -1.22 | .22 |
| **Q-Angle** | .026 | .010 | .85 | .40 | .020 | .010 | .64 | .52 |
| **Navicular Drop** | -.017 | .018 | -.57 | .57 | -.020 | .018 | -.65 | .52 |
| **Quadriceps** | -.011 | .554 | -.36 | .72 | .045 | .722 | 1.11 | .29 |
| **Hip Ext. Rotators** | -.023 | 1.426 | -.73 | .47 | .041 | 1.931 | .97 | .33 |
| **Hip Int. Rotators** | -.052 | 1.264 | -1.70 | .09 | -.026 | 1.822 | -.58 | .57 |
| **Hamstrings** | -.067 | 1.008 | -2.17 | .03 * | -.070 | 1.387 | -1.65 | .10 |
| **Gluteus Maximus** | -.005 | .717 | -.18 | .86 | .031 | .786 | .91 | .37 |
| **Gluteus Medius** | -.081 | .646 | -2.6 | .01 | -.094 | .847 | -2.32 | .02 * |

* Statistically significant. [1] Univariate betas are not adjusted for any other variable; multivariate betas are adjusted for any other variables listed in the table.

with an increased risk of injury. The error of measurement for the LESS score is greater than observed gender differences, suggesting that individual variability may limit the predictive capacity of the LESS. However, the ability of the LESS to predict injury in the military academy population is an area of ongoing study.

### Implications for injury risk based on Landing Error Patterns

While singular aspects of jump-landing technique contribute to high-risk landings, it is possible that a combination of multiple factors is more predictive of overall risk. We were able to determine common landing-error patterns for females and males using factor analysis. Strikingly, each error pattern detected has been suggested in previous literature to contribute to ACL injury: 1) decreased sagittal flexion at initial ground contact (Chappell et al., 2007); 2) valgus knee (Ford et al., 2003; Hewett et al., 1999; 2005) and feet wide at initial contact; 3) toes out and knees flexed at initial contact (DiStefano et al., 2009); 4) heelstrike landing and asymmetric footstrike landing (Boden et al., 2009); and 5) lack of sagittal flexion over the landing (Chappell et al., 2007). While both male and female cadets exhibited these combinations of high-risk movement, clear gender tendencies towards different patterns were detected (Table 2). Similar to previous reports, 42.6% of females in our cohort exhibited shallow sagittal flexion angles (trunk, hip, and knee) at ground contact (Factor 1) and 44.9% demonstrated poor knee flexion displacement over the entire landing phase (Factor 5). These flexion faults and propensity towards valgus during landing are consistent with many prior investigations (Chappell et al., 2002; 2007; Colby et al., 2000; Malinzak et al., 2001). In contrast to these findings, a recent study reported females had increased knee flexion at the time of ACL injury versus males (Krosshaug et al., 2007). However, knee and hip flexion may be task-dependent, which may explain the differing results.

We also found that females were more likely than males to land with an excessively wide stance in combination with knee valgus (Factor 2). This has not been previously reported in traditional biomechanical investigations. This wider landing stance may represent an adaptive precursor to subsequent valgus collapse, or it may simply reflect a wider average pelvic width in female cadets. We are directly measuring pelvic width in an ongoing study. Analysis of that data may allow us to better describe the phenomenon of wide landing stance in females.

Males exhibited different landing-error patterns than females. The most common male factor was heel-strike landing/uneven footstrike during landing (Factor 4), which occurred in 44.1% of our male population. Males were also more likely than females to land with “toes-out” (tibial external rotation) (Factor 3). These male error patterns have only recently been reported (Boden et al., 2009; Krosshaug et al., 2007) and are less familiar, perhaps less understood than female themes. While cadaveric and biomechanical modelling studies suggest that ACL strain is greater with knee internal rotation, analyses of actual injury mechanism describe an external rotatory force on the knee, suggesting this position is indeed high-risk (Shimokochi and Shultz, 2008). The effects of asymmetric foot strike and a heels-first landing are less discussed in ACL injury literature. One possible implication comes from preliminary work by Boden and colleagues who propose that a flat-foot landing reduces the ability of the calf muscles to dampen the ground reaction forces before they reach the knee (Shimokochi and Shultz, 2008).

### Predicting poor landing

In addition to classifying common patterns of movement, we attempted to identify relationships between measured anthropometric and strength elements and observed landing movement patterns. In the univariate analysis of individual variables, our results suggest that low BMI contributes more to jump-landing movements in male cadets than in female cadets. The relationship between this finding and previous reports of higher BMI being associated with increased injury in military and other populations is unclear (Jones et al., 1986; Knapik et al., 1991; Uhorchak et al., 2003). One possible explanation is that fatigue could preferentially worsen movement patterns in those with high BMI. Future studies comparing movement patterns under fatigued and non-fatigued conditions would facilitate further analysis. We also found that hip rotator strength exerts minimal influence on poor landing technique in either gender. This appears to contrast with recent thinking in injury prevention and rehabilitation where strengthening hip rotators is thought to reduce injury susceptibility (Hewett et al., 1999; Mandelbaum et al., 2005). Our pending analysis of traditional biomechanical measures during the jump-landing task may help explain these apparently contradictory results.

Most importantly, our results clearly demonstrate that muscle strength and anthropometric factors do NOT contribute significantly to landing movement patterns as measured by the LESS. Multivariate analysis showed very little contribution from anthropometric and strength values to overall movement patterns ($R^2$ = 0.016 for males, 0.014 for females). This is a novel finding. The primary tenants of many ACL injury prevention programs aver that increased lower extremity muscular will translate to improved movement patterns during athletic manoeuvres. In contrast, our findings suggest that simply changing an athlete's alignment, BMI, or muscle strength may not ultimately improve his or her movement patterns. Rather, landing movements seem to be primarily determined by characteristics other than strength, alignment, or body mass. Future investigations should verify this lack of correlation using traditional biomechanical methods. If confirmed, the absence of a correlation in anthropometrics and muscle strength with an individual's movement pattern would necessitate a paradigm shift in future injury prevention intervention design.

### Study limitations

We caution that the use of a military population may limit the generalizability of these results to all populations of young athletes. Specifically, the overall athleticism, BMI, or fitness of the military academy population may be significantly different than that of other populations. Additionally, although we have measured landing movement patterns in terms of "errors"—a common practice in qualitative movement screening—we recognize that differences in movement patterns cannot definitively be classified as errant unless prospectively linked to injury risk.

## Conclusion

Male and female military cadets have differences in jump-landing technique as assessed through a qualitative movement screen. Females demonstrate distinct landing movement patterns versus males. Landing-error patterns more common in males and those more common in females contain features that have been previously postulated to increase ACL injury risk. Most importantly, BMI, navicular drop, Q-angle, and muscular strength do not significantly predict movement patterns in either male or female cadets. We are collecting ACL injury incidence data from this cohort over their 4-year academy careers. This injury data may allow us to link prospective, modifiable risk factors with LESS scores, and ultimately with the risk of subsequent ACL injury.

### Disclosure

The views expressed here are those of the authors and do not represent the policy of the United States Air Force or Department of Defense.

## References


Arendt, E. and Dick, R. (1995) Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of literature. *American Journal of Sports Medicine* **23**, 694-701.

Arendt, E.A., Agel, J. and Dick, R. (1999) Anterior cruciate ligament injury patterns among collegiate men and women. *Journal of Athletic Training* **34**, 86-92.

Bjordal, J.M., Arnly, F., Hannestad, B. and Strand, T. (1997) Epidemiology of anterior cruciate ligament injuries in soccer. *American Journal of Sports Medicine* **25**, 341-345.

Boden, B.P., Torg, J.S., Knowles, S.B. and Hewett, T.E. (2009) Video analysis of anterior cruciate ligament injury: abnormalities in hip and ankle kinematics. *American Journal of Sports Medicine* **37**, 252-259.

Boling, M.C., Thigpen, C.A. and Padua, D.A. (2005) Item specific reliability analyses of the Landing Error Scoring System (LESS). *Medicine & Science in Sports & Exercise* **37**, S124.

Brody, D. (1982) Technique in the evaluation and treatment of the injured runner. *Orthopedic Clinics of North America* **13**, 541-558.

Chappell, J., Yu, B., Kirkendall, D. and Garrett, W. (2002) A comparison of knee kinetics between male and female recreational athletes in stop-jump tasks. *American Journal of Sports Medicine* **30**, 261-267.

Chappell, J.D., Creighton, R.A., Giuliani, C., Yu, B. and Garrett, W.E. (2007) Kinematics and electromyography of landing preparation in vertical stop-jump: risks for noncontact anterior cruciate ligament injury. *American Journal of Sports Medicine* **35**, 235-241.

Colby, S., Francisco, A., Yu, B., Kirkendall, D., Finch, M. and Garrett, W., Jr. (2000) Electromyographic and kinematic analysis of cutting maneuvers. Implications for anterior cruciate ligament injury. *American Journal of Sports Medicine* **28**, 234-240.

Decker, M.J., Torry, M.R., Wyland, D.J., Sterett, W.I. and Steadman, J.R. (2003) Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clinical Biomechanics* **18**, 662-669.

DiStefano, L.J., Padua, D.A., DiStefano, M.J. and Marshall, S.W. (2009) Influence of age, sex, technique, and exercise program on movement patterns after an anterior cruciate ligament injury prevention program in youth soccer players. *American Journal of Sports Medicine* **37**, 495-505.

Engstrom, B., Johansson, C. and Tornkvist, H. (1991) Soccer injuries among elite female players. *Am J Sport Med* **19**, 372-375.

Fagenbaum, R. and Darling, W.G. (2003) Jump landing strategies in male and female college athletes and the implications of such strategies for anterior cruciate ligament injury. *American Journal of Sports Medicine* **31**, 233-40.

Ferber, R., Davis, I.M. and Williams, D.S. (2003) Gender differences in lower extremity mechanics during running. *Clinical Biomechanics* **18**, 350-357.

Ford, K.R., Myer, G.D. and Hewett, T.E. (2003) Valgus knee motion during landing in high school female and male basketball players. *Medicine & Science in Sports & Exercise* **35**, 1745-1750.

Ford, K.R., Myer, G.D., Toms, H.E. and Hewett, T.E. (2005) Gender differences in the kinematics of unanticipated cutting in young athletes. *Medicine & Science in Sports & Exercise* **37**, 124-129.

Hewett, T.E., Ford, K.R., Myer, G.D., Wanstrath, K. and Scheper, M. (2006) Gender differences in hip adduction motion and torque during a single-leg agility maneuver. *Journal of Orthopaedic Research* **24**, 416-421.

Hewett, T.E., Lindenfeld, T.N., Riccobene, J.V. and Noyes, F.R. (1999) The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *American Journal of Sports Medicine* **27**, 699-706.

Hewett, T.E., Myer, G.D., Ford, K.R., Heidt, R.S., Jr., Colosimo, A.J., McLean, S.G., van den Bogert, A.J., Paterno, M.V. and Succop, P. (2005) Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *American Journal of Sports Medicine* **33**, 492-501.

Hughes, G., Watkins, J. and Owen, N. (2008) Gender differences in lower limb frontal plane kinematics during landing. *Sports Biomechanics* **7**, 333-341.

Jones, B.H., Knapik, J.J., Daniels, W.L. and Toner, M.M. (1986) The energy cost of women walking and running in shoes and boots. *Ergonomics* **29**, 439-443.

Knapik, J.J., Bauman, C.L., Jones, B.H., Harris, J.M. and Vaughan, L. (1991) Preseason strength and flexibility imbalances associated with athletic injuries in female collegiate athletes. *American Journal of Sports Medicine* **19**, 76-81.

Krosshaug, T., Nakamae, A., Boden, B.P., Engebretsen, L., Smith, G., Slauterbeck, J.R., Hewett, T.E. and Bahr, R. (2007)

Mechanisms of anterior cruciate ligament injury in basketball: video analysis of 39 cases. *American Journal of Sports Medicine* **35**, 359-367.
Lephart, S.M., Ferris, C.M., Riemann, B.L., Myers, J.B. and Fu, F.H. (2002) Gender differences in strength and lower extremity kinematics during landing. *Clinical Orthopaedics & Related Research* **401**, 162-169.
Malinzak, R.A., Colby, S.M., Kirkendall, D.T., Yu, B. and Garrett, W.E. (2001) A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clinical Biomechanics* **16**, 438-445.
Mandelbaum, B.R., Silvers, H.J., Watanabe, D.S., Knarr, J.F., Thomas, S.D., Griffin, L.Y., Kirkendall, D.T. and Garrett, W., Jr. (2005) Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *American Journal of Sports Medicine* **33**, 1003-1010.
Myer, G.D., Ford, K.R., Barber Foss, K.D., Liu, C., Nick, T.G. and Hewett, T.E. (2009) The relationship of hamstrings and quadriceps strength to anterior cruciate ligament injury in female athletes. *Clinical Journal of Sports Medicine* **19**, 3-8.
Onate, J.A., Guskiewicz, K.M., Marshall, S.W., Giuliani, C., Yu, B. and Garrett, W., Jr. (2005) Instruction of jump-landing technique using videotape feedback: altering lower extremity motion patterns. *American Journal of Sports Medicine* **33**, 831-842.
Padua, D.A., Marshall, S.W., Boling, M.C., Thigpen, C.A., Garrett, W.E., Jr. and Beutler, A.I. (2009) The landing error scoring system (less) is a valid and reliable clinical assessment tool of jump-landing biomechanics: the JUMP-ACL study. *American Journal of Sports Medicine* **37**, 1996-2002.
Shimokochi, Y. and Shultz, S.J. (2008) Mechanisms of noncontact anterior cruciate ligament injury. *Journal of Athletic Training* **43**, 396-408.
Uhorchak, J.M., Scoville, C.R., Williams, G.N., Arciero, R.A., St. Pierre, P. and Taylor, D.C. (2003) Risk factors associated with noncontact injury of the anterior cruciate ligament: a prospective four-year evaluation of 859 West Point cadets. *American Journal of Sports Medicine* **31**, 831-842.
Woodland, L. and Francis, R. (1992) Parameters and comparisons of the quadriceps angle of college-aged men and women in the supine and standing positions. *American Journal of Sports Medicine* **20**, 208-211.

## Key points

- Important differences in male and female landing technique can be captured using a qualitative movement screen: the Landing Error Scoring System (LESS)
- Female cadets were more likely to land with shallow sagittal flexion, wide stance width, and more pronounced knee flexion.
- Male cadets were more likely to exhibit a heel-strike or asymmetric foot-strike and to land with toe out.
- Lower extremity muscle strength, Q-angle, and navicular drop do not significantly predict landing movement pattern in male or female cadets.

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# Appendix

## LESS Item Scoring

| | LESS Item | Operational Definition | Camera View | Error Condition | LESS Score |
|---|---|---|---|---|---|
| 1 | **Knee flexion angle at initial contact** | At the time point of initial contact, if the knee of the test leg is flexed more than 30 degrees, score YES. If the knee is not flexed more than 30 degrees, score NO. | Side | No | Y=0<br>N=1 |
| 2 | **Hip flexion angle at initial contact** | At the time point of initial contact, if the thigh of the test leg is in line with the trunk then the hips are not flexed and score NO. If the thigh of the test leg is flexed on the trunk, score YES. | Side | No | Y=0<br>N=1 |
| 3 | **Trunk flexion angle at initial contact** | At the time point of initial contact, if the trunk is vertical or extended on the hips, score NO. If the trunk is flexed on the hips, score YES. | Side | No | Y=0<br>N=1 |
| 4 | **Ankle plantar-flexion angle at initial contact** | If the foot of the test leg lands toe to heel, score YES. If the foot of the test leg lands heel to toe or with a flat foot, score NO. | Side | No | Y=0<br>N=1 |
| 5 | **Knee valgus angle at initial contact** | At the time point of initial contact, draw a line straight down from the center of the patella. If the line goes through the midfoot, score NO. If the line is medial to the midfoot, score YES. | Front | Yes | Y=1<br>N=0 |
| 6 | **Lateral trunk flexion angle at initial contact** | At the time point of initial contact, if the midline of the trunk is flexed to the left or the right side of the body, score YES. If the trunk is not flexed to the left or right side of the body, score NO. | Front | Yes | Y=1<br>N=0 |
| 7 | **Stance width – Wide** | Once the entire foot is in contact with the ground, draw a line down from the tip of the shoulders. If the line on the side of the test leg is inside the foot of the test leg then score greater than should width (wide), and score YES. If the test foot is internally or externally rotated, grade the stance width based on heel placement. | Front | Yes | Y=1<br>N=0 |
| 8 | **Stance width – Narrow** | Once the entire foot is in contact with the ground, draw a line down from the tip of the shoulders. If the line on the side of the test leg is outside of the foot then score less than shoulder width (narrow), score YES. If the test foot is internally or externally rotated, grade the stance width based on heel placement. | Front | Yes | Y=1<br>N=0 |
| 9 | **Foot position – Toe In** | If the foot of the test leg is internally rotated more than 30 degrees between the time period of initial contact and max knee flexion, then score YES. If the foot is not internally rotated more than 30 degrees between the time period of initial contact to max knee flexion, score NO. | Front | Yes | Y=1<br>N=0 |
| 10 | **Foot position – Toe Out** | If the foot of the test leg is externally rotated more than 30 degrees between the time period of initial contact and max knee flexion, then score YES. If the foot is not externally rotated more than 30 degrees between the time period of initial contact to max knee flexion, score NO. | Front | Yes | Y=1<br>N=0 |
| 11 | **Symmetric initial foot contact** | If one foot lands before the other or if one foot lands heel to toe and the other lands toe to heel, score NO. If the feet land symmetrically, score YES. | Front | No | Y=0<br>N=1 |
| 12 | **Knee flexion displacement** | If the knee of the test leg flexes 45 degrees more than the angle at the position of initial contact to max knee flexion, score YES. If the knee of the test leg does not flex more than 45 degrees, score NO. | Side | No | Y=0<br>N=1 |
| 13 | **Hip flexion at max knee flexion** | If the thigh of the test leg flexes more on the trunk from initial contact to max knee flexion angle, score YES. If the thigh does not flex more on the trunk, score NO. | Side | No | Y=0<br>N=1 |
| 14 | **Trunk flexion at max knee flexion** | If the trunk flexes more from the point of initial contact to max knee flexion, score YES. If the trunk does not flex more, score NO. | Side | No | Y=0<br>N=1 |
| 15 | **Knee valgus displacement** | At the point of max knee valgus on the test leg, draw a line straight down from the center of the patella. If the line runs through the great toe or is medial to the great toe, score YES. If the line is lateral to the great toe, score NO. | Front | Yes | Y=1<br>N=0 |

| | | | | | |
|---|---|---|---|---|---|
| **16** | **Joint displacement** | Watch the sagittal plan motion at the hips and knees from initial contact to max knee flexion angle. If the subject goes through large displacement of the trunk, hips, and knees then score SOFT. If the subject goes through some trunk, hip, and knee displacement, but not a large amount, score AVERAGE. If the subject goes through very little, if any trunk, hip, and knee displacement, score STIFF. | Side | Average or Stiff (double penalty for Stiff) | Soft=0<br>Avg=1<br>Stiff=2 |
| **17** | **Overall impression** | Score EXCELLENT if the subject displays a soft landing and no frontal plane motion at the knee. Score POOR if the subject displays a stiff landing and large frontal plane motion at the knee. All other landings, score AVERAGE. | Side, Front | Average or Poor (double penalty for Poor) | Ex=0<br>Avg=1<br>Poor=2 |